MERIDIAN

CROSSING AESTHETICS

What Is Real?

GIORGIO AGAMBEN

TRANSLATED BY LORENZO CHIESA

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Crossing Aesthetics

Series founded by the late Werner Hamacher

Editor

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Giorgio Agamben

Translated by Lorenzo Chiesa

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Contents

What Is Real? 1

The Value of Statistical Laws in Physics and Social Sciences, by Ettore Majorana (*translated by Rosario Nunzio Mantegna*) 45

Notes 67

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WHAT IS REAL?

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What Is Real?

1. On the night of 25 March 1938, at 22:30, Ettore Majorana, who was regarded as one of the most talented physicists of his generation, boarded a Tirrenia steamer in Naples—where he had held the chair of theoretical physics for a year—heading for Palermo. In the words of the announcement published on 17 April in the "Chi l'ha visto?" column of the *Domenica del Corriere*, from that moment, except for unconfirmed reports and conjectures, every trace of "the thirty-one year old professor, 170 cm tall, lean, dark hair and eyes, with a long scar on the back of his hand" was lost. In spite of searches involving the police authorities and, under pressure from Enrico Fermi, the head of government in person, Ettore Majorana had disappeared forever. His relatives never accepted the possibility of suicide, which in itself seemed to convince the police that he had killed himself, and did not apply for

a declaration of presumed death, as is usual in these circumstances. Unverifiable legends then circulated about the scientist's escape to Argentina or Nazi Germany, his retreat to a monastery, and reappearance as a tramp in Sicily and Rome in the 1970s.

Every reflection on his disappearance should start from the letters Majorana wrote on the very day of his departure and the next as the only indisputable documents. A careful analysis of the texts shows that, at the very moment when he decides to disappear, Majorana seems to suggest divergent explanations for his gesture, as if he wanted to cover his tracks, intentionally leaving it open to contrasting interpretations.

On the same day of his departure he writes the following letter to Carrelli, his colleague at the University of Naples:

"Dear Carrelli, I have made a decision that was by now inevitable. It does not contain a single speck of selfishness; but I do realize the inconvenience that my sudden disappearance may cause for the students and yourself. For this, too, I beg you to forgive me; but above all for having betrayed the trust, the sincere friendship and the sympathy you have so kindly offered me over the past few months. I beg you also to remember me to all those I have come to know and appreciate at your Institute, in particular Sciuti; of all I shall preserve the dearest memories at least until eleven o'clock this evening, and possibly later too."

Majorana refers to the act he is carrying out as "my sudden disappearance," not as a suicide, and shortly after specifies that he will remember his friends from the Institute of Physics "until eleven o'clock this evening, and possibly later too." His intention to insinuate discordant explanations is already evident; "until eleven o'clock" may indeed refer to an anticipation of death, but, as has been observed, it is highly unlikely that, having the whole night ahead of him, he intended to jump in the sea half an hour after departing, when the sailors and passengers were still awake on the decks and would certainly have seen him. From this standpoint, the "possibly later too" is even more misleading, as it seems to contradict—although only hypothetically—every idea of suicide. Moreover, we should highlight the claim about the absolutely nonsubjective motivation for his decision ("it does not contain a single speck of selfishness"). That Majorana was actually not thinking about suicide seems to be proved by the only other fact that is certain: before setting off, he withdrew a considerable amount of money and brought his passport with him.

On the other hand, the letter he leaves at the hotel for his parents reads like a suicide note, although death is curiously evoked only through its repercussions with respect to dress codes: “I have only one desire: that you do not wear black. If you want to follow custom, then bear some sign of mourning but not for more than three days. After that, if you can, remember me in your hearts and forgive me.”

On 26 March, Carrelli received a laconic telegram that contradicted the letter Majorana had just sent and promised a new one: “Don’t get alarmed. Letter to follow. Majorana.” The new letter, dated “Palermo 26 March 1938-XVI” (we should notice the reference to the Fascist Era, as if it were an official document), in fact announced the imminent return of the “missing” person:

“Dear Carrelli, I hope you got my telegram and my letter at the same time. The sea rejected me and I will be back tomorrow at the Hotel Bologna traveling perhaps with this letter. However, I intend to give up teaching. Do not think I am like an Ibsen heroine, because the case is different. I am at your disposal for further details.”

Once again the allusion to the sea’s rejection may suggest an abandoned intention to commit suicide (but also the intention to embark upon a sea voyage); however, the decision to disappear is now replaced by the decision to give up teaching—which is presented as somehow equivalent. As in the first letter where disappearance is at stake, emphasis is being placed on the non-psychological motivations for this resignation ("Do not think I am like an Ibsen heroine, because the case is different"). "The case is different"; Majorana implicitly suggests to his friend that it is a matter of understanding the particular nature of the "case" in question.

Majorana's behavior duly disproved even the content of this letter. Although according to the shipping line the return ticket had been used and a nurse who knew him said she had glimpsed him on a street in Naples, Majorana did not return to the Hotel Bologna nor did he show up at the university to resign from his position. Now he had truly disappeared forever.

The first conclusion we can draw from the examination of the letters is that the reality of facts never duly corresponds to the reality they evoke, which in turn lends itself to divergent interpretations, of which the author could not be unaware. Majorana did not disappear after the first letter, which announced his final parting, and did not reappear after the second, which communicated his reappearance. Nor did he kill himself, as seemed implicit in the letter to his relatives. However, the only certain thing is that he actually and irrevocably disappeared, and that he relinquished his position in theoretical physics in an equally irrevocable manner, but in both cases in ways other than those suggested by the letters.

In other words, the disappearance of Majorana is equally certain and improbable (in the literal sense of the term, it cannot be proved and ascertained at the level of facts). The only thing that remains the same is the claim about the non-psychological and non-subjective motivations for both his disappearance and resignation. His "case" is in every sense truly "different."

2. In 1975 Leonardo Sciascia devoted an exemplary book to the possible motivations for Majorana's disappearance, which rightfully rescued such an extraordinary case from neglect. Sciascia carefully reconstructs Majorana's personality, his philosophical and literary inclinations (according to Amaldi's testimony, he passionately read Shakespeare and Pirandello), his difficult relationship with Fermi, and the fruitful meeting with Heisenberg in Leipzig in 1933. Sciascia's hypothesis is that the young scientist—defined by Fermi himself as a genius comparable with Galileo and Newton, yet lacking common sense—realized what in 1934 Fermi was unable to realize—that is, the fact that the experiments with radioactivity carried out by the physicists in Rome could lead to the splitting of the uranium atom. "According to Fermi, Majorana was a genius. And why then should he not have perceived or sensed what scientists of the third,

second, and even first rank still failed to perceive or did not sense? Moreover as early as 1921, a German physicist, referring to Rutherford's atomic research had warned: 'We are living on an island of Pyrolixyn,' adding that, thank God, the match had not yet been found to set it on fire. (It obviously never occurred to him that, once it had been found, one might still have refrained from lighting it!) So why shouldn't a physicist of genius who, fifteen years later, found himself confronted with the potential—although unacknowledged—discovery of nuclear fission have been able to realize that the match existed and—since he lacked common sense—have turned away from it in dismay and terror?"[1]

Sciascia has no difficulty in recalling that, bombarding the uranium atom with neutrons, Fermi and his collaborators unwittingly carried out nuclear fission, and that, in a short article from 1934 Majorana might have read, a German chemist—Ida Noddack—had suggested that what resulted from the experiment were not new transuranic elements—as Fermi wrongly believed—but the disintegration of the uranium atom into several fragments of a given size. From here it is but a short step to imagining the possible and disastrous consequences of this splitting; Sciascia quotes the testimony of Majorana's sister, according to whom Ettore would sadly repeat that "physics is on the wrong track." The book closes with a visit to a Carthusian monastery, where the scientist supposedly retreated until his death—Sciascia proposes this hypothesis not as a factually verifiable certainty but as a "metaphysical experience."[2]

3. At a certain point in the book, Sciascia quotes a passage from an article, written by Majorana in the years following his return from Germany (1933) and prior to his being appointed to a chair at the University of Naples (1937), the conclusion of which seems to him "profoundly suggestive, in terms of disquiet and fear"—although he curiously fails to account for his statement. In that period Majorana almost entirely broke off his relationship with Fermi and the Institute of Physics and rarely left his house. "He wrote for hours, for hours and hours, day and night—whether about physics or philosophy the fact remains that nothing survives of all he wrote apart from two brief papers."[3] The first, devoted to a symmetric theory of electrons and positrons, was published by Majorana in 1937; the second—quoted by Sciascia and with which we will specifically deal here—was published in 1942, four years after the scientist's mysterious disappearance, in the March issue of the journal *Scientia* under the title "The Value of Statistical Laws in Physics and Social Sciences."

The analogy suggested by the title between the statistical laws of physics and the statistical laws of the social sciences is developed in the text in a way that merits attention. The article in fact contains a reflection on the transformation of physics as a consequence of the abandonment of the determinism of classical mechanics in favor of a purely probabilistic conception of reality. This transformation of the conception of nature in quantum physics implies also a change in the character of the statistical laws it invokes. While in classical physics the latter were founded on the decision not to know all the details of the initial conditions of physical systems and did not call into question the determinism of natural laws, quantum mechanics involves a radical shift in the very notion of law, which Majorana expresses as follows:

"There are no laws in nature that express an inevitable series of phenomena; even basic laws concerning elementary phenomena (atomic systems) have a statistical character. They only allow us to establish the *probability* that a measurement performed on a system prepared in a given way will give a certain result. This occurs independently of the means we have to determine the initial state of the system with the highest possible accuracy. These statistical laws indicate a real deficiency of determinism. They have nothing in common with the classical statistical laws where the uncertainty of results derives, for practical reasons, from a voluntary refusal to investigate the initial conditions of physical systems in their most minute aspects."

The other aspect of quantum mechanics on which Majorana dwells is the one that led Heisenberg to define the uncertainty principle and is formulated by Majorana in the following way:

"Any experiment performed on an atomic system exerts a finite perturbation on it that cannot be eliminated or reduced for reasons of principle. The result of any measurement seems, therefore, to be concerned with the state the system is led to during the experiment rather than with the unknowable state of the system before being perturbed."

Heisenberg derived the necessity of introducing statistical laws into quantum mechanics from this impossibility of accurately describing the state of an atomic system. In any case, Majorana is indeed trying to understand the new sense of these laws and their analogy with the laws of social statistics.

He exemplifies this analogy by means of the probabilistic laws that concern the "mortality rate" of the atoms that are transformed in radioactive processes. These transformations do not depend on the age of the atom and have a purely probabilistic character that rules out any causal determinism. "It was possible to verify through direct statistical measurements and applications of probability calculus that single radioactive atoms do not undergo any reciprocal or external influence with regard to the moment of transformation. In fact the number of disintegrations occurring in a given time interval is subjected to exclusively random fluctuations, that is, to the probabilistic character of the individual law of transformation." Although, here, at first sight, there does not seem to be an analogy with the facts studied by social statistics (for instance, the life-expectancy tables in a given population), Majorana on the contrary suggests that the correspondence is here no less cogent than that which was demonstrated a few pages earlier with regard to the statistical laws of classical physics.

"The introduction into physics of a new kind of statistical—or better, simply probabilistic—law, which is concealed behind the statistical laws to which we are accustomed and replace a supposed determinism," not only does not oblige us to rule out the analogy with the social statistical laws, but provides the latter with a further foundation. The objection according to which the disintegration of a radioactive atom is, unlike social facts, an isolated and unpredictable phenomenon—which may happen after thousands of years—is in fact not insurmountable. "The disintegration of a radioactive atom can force an automatic counter to record it as a mechanical effect, which is made possible by an appropriate amplification.

Ordinary laboratory devices are therefore sufficient to prepare a complex and conspicuous chain of phenomena that is *commanded* by the accidental disintegration of a single radioactive atom. From a strictly scientific point of view, nothing prevents us from considering it plausible that an equally simple, invisible, and unpredictable vital fact lies at the origins of human events. If this is the case, as we believe it is, then the statistical laws of the social sciences enhance their function, which is not only that of empirically establishing the outcome of a great number of unknown causes, but especially that of providing an immediate and concrete testimony of reality. The interpretation of this testimony requires a special art, which is not the least significant support of the art of government."

We need to think very carefully about this passage. First of all, the fact that the term "commanded" is in italics is important: "Ordinary laboratory devices are therefore sufficient to prepare a complex and conspicuous chain of phenomena that is *commanded* by the accidental disintegration of a single radioactive atom." Here it is possible to read something that goes beyond an allusion to nuclear fission, which a few years later will lead the team directed by Oppenheimer and Fermi to build the first atomic bomb. Majorana seems to suggest that it is precisely the exclusively probabilistic character of the phenomena at stake in quantum physics that authorizes the investigator's intervention, that is, renders him capable of "commanding" the phenomenon itself to move in a certain direction. The principle of uncertainty here reveals its true meaning, which is not limiting knowledge, but justifying the intervention of the investigator as inevitable. If experimenting with and measuring an atomic system exerts on it an ineliminable perturbation, then what is at stake in the experiment is not so much the knowledge of that system as, first and foremost, the modification it undergoes due to the measuring instruments. In Majorana's words, "the result of any measurement seems, therefore, to be concerned with the state the system is *led to* during the experiment rather than with the unknowable state of the system before being perturbed." And we understand why Majorana defines this aspect of quantum physics as "more disquieting . . . than the simple lack of determinism"; it is precisely the lack of classical physics' determinism at the quantum level that enables, or rather forces, the investigator to "command" or "determine" the state of the system to an unheard-of degree.

At this stage, the analogy Majorana establishes with the procedures of social statistics becomes all the more significant. The apparently enigmatic sentence that concludes the article ("The interpretation of this testimony requires a special art, which is not the least significant support of the art of government") acquires in this perspective a particular meaning; just as the probabilistic laws of quantum mechanics aim not at knowing but at "commanding" the state of atomic systems, so the laws of social statistics do not aim at the knowledge of social phenomena but at their very "government." In both cases, statistics is "a special art, which is not the least significant support of the art of government."

It is then possible that Sciascia's hypothesis on the motivations that prompted Majorana to abandon physics needs to be corrected and expanded; while it is not certain that Majorana glimpsed the consequences of the splitting of the atom, it is certainly the case that he clearly saw the implications of a mechanics that renounced every non-probabilistic conception of the real. Science no longer tried to know reality, but—like the statistics of social sciences—only intervene in it in order to govern it.

4. In the early months of 1941, one year before the publication of Majorana's article, Simone Weil began to write in Marseille an essay titled "La science et nous," which is essentially a critique of quantum physics. The heterogeneity of the latter with respect to classical physics is placed in stark relief in the introduction: "To us, people of the West, a very

strange thing happened at the turn of the century; without noticing it, we lost science, or at least the thing that had been called by that name for the last four centuries. What we now have under this name is something different, radically different, and we do not know what it is."[4]

According to Weil, classical science was constituted by considering every natural phenomenon in the light of a single notion, derived from that of work: the notion of energy. If I want to carry out work, for instance, moving a body from one place to another, I need to use a certain amount of energy; while, on the other side, the body in question will necessarily have to go through all the intermediate states between the initial and the final one. "Building upon the discoveries of Bernoulli and D'Alembert, Lagrange came to define by a single formula every possible state of equilibrium and motion of any system of bodies subjected to any force; this formula refers only to distances and forces or, what amounts to the same thing, to masses and velocities."[5] Classical physics added to the notion of energy thus defined an equally necessary principle of entropy. "This necessity derives from time itself and consists in the fact that it has a direction, in that the orientation of a transformation is never indifferent, whatever happens. We experience this necessity, not only through the aging that holds us ever more firmly in its grasp and never abandons us, but also through everyday events. A minimal moment or effort is sufficient to throw a book off the table, mix up a pile of papers, stain some clothing, crumple some linen, burn a field of wheat, or kill a man. But it takes considerable effort and time to put a book up on the table, put papers in order, clean clothing, and iron linen; a year of toil and care is necessary to produce a new harvest from the field, and one cannot make a dead man come back to life."[6]

This means that, in every phenomenon in which a transformation of energy is produced, it is not possible exactly to reestablish the initial state once the phenomenon has been accomplished. The second law of thermodynamics, formulated by Clausius, gave mathematical form to this reality through the fiction of a notion—entropy—that necessarily increases in every system in which a change occurs, so that, if external factors do not intervene, energy is dispersed and moves from order to disorder. "Such was the crowning achievement of classical science, which therefore claimed that it would be possible by calculations, measurements, and numerical equivalents to read across all phenomena that are produced in the universe simple variations of energy and entropy conforming to a simple law."[7] These variations amounted to necessary and continuous processes, and therefore one could say that classical science was based on the same necessity and continuity with which we are confronted every time we carry out work.

Quantum theory radically calls into question this correspondence between physical laws and the image of the world founded on the experience of work. "Twentieth-century science is classical science after something has been taken away from it. Taken away, not added. . . . We have subtracted from it the analogy between the laws of nature and the conditions of work, which is to say, its very principle; it is this that the quantum hypothesis has decapitated."[8] In classical physics, "energy is a function of space, and space is continuous; it is continuity itself; it is the world considered from the standpoint of continuity; it is things insofar as their juxtaposition implies something continuous."[9] Planck's formula and constant introduced discontinuity into energy at the precise point at which, according to Weil, it cannot take place. In fact the appearance of discontinuity in physics is connected with the investigation of atomic systems, which thus reveal themselves to be subject to laws that are completely different from those of macroscopic systems. Moreover, according to Weil, the introduction of discontinuity entailed the emergence of probability: "Discontinuity, number, smallness; this is enough to make the atom appear, and the atom has come back to us along with its inseparable entourage, that is, chance and probability. The appearance of chance in science has been seen as scandalous; we asked where it came from and did not realize that the atom brought it; we forgot that, already in the ancient world, chance went along with the atom, and failed to realize that it could not have been otherwise."[10]

In the pages that immediately follow, the decisive factor that has led to quantum physics is not so much discontinuity as the calculation of probabilities. In a curious reversal, probability is not a function of the discontinuity of atomic systems, but rather the latter is derived from the former. Examining Planck's writings—which Weil quotes repeatedly—"it clearly appears that what introduced discontinuity is not experience . . . but only the usage of the notion of probability."[11] In an article published in *Cahiers du Sud* in December 1942, this genealogical primacy of probability is stated once again: "One wonders whether it is not the very nature of the calculation of probabilities, which originates from the game of dice, and consequently from numerical relations, that led Planck to introduce whole numbers into his formula."[12] A few pages later, Weil adds: "When scientists came across discontinuity, they still went on reducing everything to variations of energy; they simply located discontinuity within energy, depriving it of all meaning. . . .

The difficulty of establishing through the notion of probability a bridge between the world we are given and the hypothetical and purely mechanical world of atoms did not embarrass them; the consequences of quantum theory, which originates from the study of probability, prompted them to locate probability within the atoms themselves."[13] At this point, Simone Weil focuses on an examination of this concept.

5. Weil begins by referring the concept of chance [*caso*] back to that of necessity:[14] "We are often mistaken about chance [*hasard*]. Chance is not the opposite of necessity and is not incompatible with it. On the contrary, chance always and only appears in relation to necessity. If we suppose a certain number of different causes producing effects according to a rigorous necessity, and if there appears in these effects a set that has a certain structure, we will obtain chance if we cannot group the causes in a set of the same structure. Due to its shape, a dice can only land in six ways; while, on the other hand, there is an unlimited variety of ways of throwing it. If I throw a dice one thousand times, its landings can be distributed into six classes that have numerical relations between them; the throws cannot be distributed in the same way. Moreover, I cannot presume the least deficiency in the texture of the mechanical necessity that determines

at each turn the movement of the dice. If I throw the dice once, I ignore what the result will be, not because of an indetermination of the phenomenon, but because this is a problem where in part I do not know the givens. . . . In these games, the set of causes has the power of continuity, which means that the causes are like the points of a line; the set of the effects is instead defined by a small number of different possibilities."[15]

If chance is, in this sense, inseparable from necessity, then probability is in turn inseparable from chance, and thanks to probability chance becomes a quantity that may be controlled in experiments. "When, in games of chance, I consider the continuous set of causes and the small number of categories into which their effects can be distributed, I affirm that, although each effect proceeds rigorously from a cause, there is absolutely nothing in the set of causes that corresponds to these categories; that is what it means to say that there is chance. Hence these categories all have an identical relation to the set of causes that, at the same time, is indifferent to them. That is what it means to say that they are equally probable. The notion of probability always implies a distribution into equal probabilities. . . . With respect to the relation of probability to experience, it is analogous to the relation of necessity to experience. Experience presents an image of necessity when, by varying a cause, one obtains effects that vary according to a function; it presents an image of probability when the distribution of effects into categories gets closer and closer to the proportions indicated by calculation as the effects accumulate."[16]

At this point, Weil reconstructs the way in which Planck was led to introduce probability and discontinuity into the theory of physics through his constant, and how this principle was generalized in quantum mechanics: "There is a natural transition between the notion of entropy and that of probability, for the fact that if a system, isolated from external disturbance, can pass from state A to state B by means of any chain of intermediaries, but not the other way round, then state B is more probable than state A."[17] At the precise moment Planck was elaborating these ideas, chance appeared in the sphere of the atom. The observation of Brownian motion in fact showed that a fluid that appears to be in a state of equilibrium at the macroscopic level is not so at all at a microscopic level, and that, in general, a system defined in a certain necessary way on the first level corresponds on the molecular level to a plurality of possible combinations. "If we try to transfer necessity into the atomic sphere, the relation between two states of a system defined at a macroscopic level is no longer a necessity but a probability. This is not because of any flaw in causality, but only because of an effect of the oscillation of thought between the two levels, through a process analogous to that of a game of dice. A natural movement of thought led us to bring together the two probabilities simultaneously arising in our minds—the one linked to entropy and the other linked to atoms—and to consider them as one and the same probability. . . . However, since the calculation of probabilities is a numerical calculus, it was stipulated that the combinations of atoms are, so to speak, discrete and that their quantity is a number; this is the point of rupture with classical science."[18]

It is evident that Simone Weil is here making a decisive criticism of the idea that the statistical laws of quantum physics are not the consequence of an incomplete knowledge of the data concerning the state of a given system, but refer back—in Majorana's words—to a deficiency of determinism in reality. The paradigm of necessity and of the cause-effect relation remains valid for quantum physics, and the superiority of classical physics is based precisely on this: "Some splendid verses of Lucretius suffice to give us a sense of what is purifying in the sight and experience of necessity; well-endured affliction is a purification of this kind, as is classical science also a purification, if one makes good use of it, for it tries to read through all appearances this inexorable necessity that makes of the world a world where we do not count, a world where we work, a world indifferent to desire, aspirations, and the good; it is the study of the sun that shines indifferently on the just and the unjust."[19]

According to Weil, renouncing necessity and determinism in the name of probability, quantum mechanics has purely and simply renounced science. If the cause of the rupture with the continuous model of classical physics was the numerical character of the calculation of probabilities, Weil wonders at this point why scientists did not choose to work on the very notion of probability in order to elaborate a model of calculation that is not founded on discontinuity but on continuity—instead of changing the theory of physics from top to bottom.[20]

6. The same scientists who had contributed to laying the foundations of quantum physics themselves advanced criticisms of its probabilistic character. For instance, Louis De Broglie, who developed the theory of the simultaneously corpuscular and wavelike character of quantum particles, attempted to provide a non-probabilistic interpretation of this duality, which was by and large more compatible with the notions of classical physics. But the prevalent interpretation promoted by Niels Bohr, Max Born, Werner Heisenberg, and Paul Dirac rejected it. De

Broglie claimed that this interpretation "considered both waves and particles, but in a way which relegated both to a sort of phantom existence and without any attempt to connect the two in a clear spatio-temporal model. The particle itself no longer had a fixed position, velocity, or trajectory—it could mark its presence only by revealing a given position, energy, and momentum at the moment of measurement. At any given moment, the particle may therefore be said to have a host of *possible* positions and momenta, each of which has a given probability of being found on measurement. Side by side with this evanescent particle which had ceased to be a definite object in space and time, there now existed a regular wave that had lost all the physical properties of the classical wave. The wave had become a purely mathematical function representing the probability of obtaining certain results from measurements of the particle."[21]

Even Einstein, who decisively contributed to quantum theory, had until the end reservations about an exclusively probabilistic interpretation of it. In May 1935, he published with Boris Podolsky and Nathan Rosen an article in *Physical Review* titled "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?," in which he argued that, insofar as it is the case that when two physical quantities are given in quantum mechanics, the knowledge of the one precludes the knowledge of the other (following Bohr's complementarity principle), either the description of reality provided by the wave function is not complete or the two quantities exist simultaneously. The article, which ended by affirming the possibility of a complete physical theory, produced an immediate reaction from Bohr in the same journal. Bohr founded the complementarity principle—according to which it is impossible to assign defined values to two regularly combined variables, such as the velocity and the position of a particle—on the quantum principle that the interaction between the measuring instruments and the object under examination necessarily implies the abandonment of the classical idea of causality. In quantum mechanics, natural laws never lead to a complete determination of what occurs in space and time, and every event depends on chance and probability. At the end of his article, somehow maliciously but not unreasonably, Bohr recalls that what Einstein intended to criticize in the probabilistic character of quantum physics was nothing other than a consequence of his general theory of relativity: "This new feature of natural philosophy means a radical revision of our attitude as regards physical reality, which may be paralleled with the fundamental modification of all ideas regarding the absolute character of physical phenomena, brought about by the general theory of relativity."[22] But this modification of reality in a statistical sense was precisely the difficulty Einstein could not resolve throughout his life—and his reasoning was not without contradictions.

A few months after the polemic between Einstein and Bohr, Erwin Schrödinger—who, among the founders of quantum mechanics, had arguably the strongest philosophical background—intervened and proposed an experiment that became known as "the cat paradox." He starts off by restating that, according to the prevailing interpretation, it is impossible to describe objects as one does in classical physics, and we therefore need to provide a purely probabilistic representation of them. Before the observer intervenes and measures the variables of a physical system, they have no definite value, and measuring them does not mean verifying the value they objectively have. The measurement irrevocably modifies the system, but prior to it, in probabilistic representation, the observable particle can be, so to speak, found simultaneously in every position it can assume, or, in the case of two distinct states, in any of their combinations.

Here Schrödinger introduces the "ridiculous case" of a cat that we are compelled to suppose is both alive and dead at the same time: "One can even set up quite ridiculous cases. A cat is penned up in a steel chamber, along with the following device (which must be secured against direct interference by the cat): in a Geiger counter there is a tiny bit of radioactive substance, so small, that perhaps in the course of the hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed. The first atomic decay would have poisoned it. The psi-function of the entire system [i.e., the function that expresses its probabilistic state] would express this by having in it the living and dead cat (pardon the expression) mixed or smeared out in equal parts."[23] It is only by opening the box that the observer forces the system (the cat) definitively to pass into one of the two states (alive or dead).

It is evident that, as was suggested by Simone Weil, the paradoxes in question in quantum mechanics derive from the unconditional assumption of probabilistic conceptions, which are not matched by an adequate reflection on the very nature of the notion of probability. For both the supporters of the orthodox theory and their critics, the state of the system before and after observation is not a real but a probabilistic state; however, they seem to produce a representation of this state and argue as if probability were a very special kind of reality, which one can think only in a paradoxical way (for example, as if a particle were at the same time in both state A and state B). But is it correct to represent the probable as if it were something that exists? In other words, what is at stake is a problem concerning the ontology of the probable—or the possible, since probability is nothing other than a possibility qualified in a certain way. Following Weil's suggestion, at this point it is therefore necessary to focus on the very notion of probability.

7. The calculation of probabilities was elaborated in the context of a consideration of dice games. The treatise *De ludo aleae*, written by Gerolamo Cardano in 1575 but published only after his death, in 1663, enunciates its foundations for the first time. Cardano starts by distinguishing between games of dexterity—such as ball games—games of strength—such as wrestling and discus throwing—and games of chance—including cards and dice games. Cardano was a compulsive gambler and, in his autobiography, he confesses to playing dice every day for twenty-five years, "with the loss at once of reputation, time, and money." However, he suggests that experience showed him that dice games are useful remedies against grief and death: "In times of great anxiety and grief, gambling is not only permissible, but even

beneficial. . . . When it seemed to me after a long illness that death was close at hand, I found no little solace in playing constantly at dice."

The "fundamental principle" (*principale fundamentum*) of dice games is the equality (*aequalitas*) of conditions, not only among players, who should not be too dissimilar in terms of power, money, and fortune, but first and foremost in the dice themselves, which should not be loaded. In Chapter IX, "De unius aleae iactu" (On throwing one dice), Cardano approaches a definition of probability. "The dice has six faces; in six casts (*in sex revolutionibus*) every single point should take place (*evenire deberent*)."[24] This means that, if the dice is not loaded and the condition of *aequalitas* respected, the probability of each point is 1/6; but Cardano writes "should," since he knows that as a matter of fact it may happen that the same number presents itself more often than others (this led some scholars to claim that he somehow intuited the law of large numbers, on which every statistical calculation is based). Chapter XIV thus articulates what could be regarded as a more explicit definition of probability: "There is one general rule, namely, that we should consider the whole circuit [for Cardano, the circuit is the set of possible results] and the number of those casts that represents in how many ways the favorable result can occur, and compare that number to the remainder of the circuit, and according to that proportion should the mutual wagers be laid."[25] Once he has established that, in the case of two dice, the number of the circuit is 36 (and 216 in the case of three), Cardano can calculate in specific tables the probabilities of the various points—for instance, given that the point three can be obtained only in one way (2+1) and the point ten in two ways (5+5 and 6+4), the probabilities are different in the two cases.

8. After elaborating these tables, Cardano claims that it is impossible to eliminate luck from the dice, "which makes some people benefit from unexpected cases and impoverishes others because of what they were expecting,"[26] but a careful reading of his short treatise allows us to extrapolate the first features of a theory of probability. First of all, as Simone Weil sensed, the notion of probability presupposes a distribution among equal probabilities (that is, the principle of *aequalitas*, which Cardano enunciates in a still vague way). If we acknowledge chance, that is, the fact that the relationship between the events under examination (the landing of the dice) and their cause (the throw) is absolutely indifferent, this can be expressed by saying that such events are all equally probable. As Poincaré observed, from this it follows that the definition of probability is circular, since it contains the term that

needs to be defined: "The probability of an event is the ratio of the number of cases favorable to the event to the total number of possible cases, provided that these are all equally probable."[27]

This circularity implies that the notion of probability never refers to a certain real event (a given throw of the dice as actual) but only to the event as considered in its pure possibility. In other words, probability presupposes that the human mind is capable of considering an event as possible and, moreover, as equally possible with respect to the class of events in question. This is the convention without which the calculation of probabilities is unthinkable. However, the fact remains that this calculation cannot concern an individual case, but only an imaginary being [*ente di ragione*] we call the "probable case."

Let us consider the case of the roulette wheel evoked by Poincaré; a small ball is thrown onto a board divided into a large number of sections of equal size, painted alternately red and black. The probability that the ball stops on the red is 1/2. But this does not at all allow us to assume that the result of a given throw will be red even after six, ten, or twenty consecutive results of black. Only after a great number of throws shall we be able to ascertain that the average of the results is distributed according to the expected probability of 1/2. This is the meaning of the law of large numbers

Bernoulli enunciated in his 1713 *Ars coniectandi*, which forms a system with the law of the equality of probabilities and confirms the principle that probability does not concern a real given event but only the tendency to infinity of the number of examined samples.

In other words, the principle that supports the calculation is the replacement of the realm of reality with that of probability, or the superimposition of the one upon the other. Those who act with probability in mind abide by this superimposition and are compelled to acknowledge, more or less tacitly, that although it never determines an individual real case, it can nonetheless influence to some extent their decisions with respect to reality, in spite of the evident paralogism. Modern science—and every single human being with it—directs its decisions according to a criterion that cannot directly refer to the case in question, but only to a "probable case" that can coincide with the former only "randomly" [*casualmente*].

If the probability of the plane I have to take crashing is 1/1000, then the crashing of that precise plane is an "unlikely case," which remains such even after the plane has actually crashed. In Wittgenstein's words, the world is only "all that is the case" and probability can therefore never exist as such, since it is nothing other than that very world, a world whose reality is suspended in order for us to be able to govern it and take decisions about it. What we call “case” is the fiction according to which the probable and the possible “fall” into reality, while the opposite is true; when considered in a certain way, it is the real that suspends its reality and can thus fall into itself as merely probable.

9. Perhaps there is no other text in which the aim and nature of the calculation of probabilities appear more clearly than in the 1654 correspondence between Pascal and Fermat. Antoine Gombault, Chevalier De Méré, proposed to Pascal the problem of the so-called interrupted game: if a dice game is interrupted before the final victory of one of the two players, how should the stake be fairly divided? Pascal’s solution is founded on the possibility of finding, by means of a calculation of risk (Pascal uses the term *hasard* and not *probabilité*, which he reserves for theology), the “proper value of each game” (*la juste valeur des parties*).

“This is the way I go about it to know the value of each of the games when two gamblers play, for example, in three games, and when each has put 32 pistoles at stake. Let us suppose that the first has won two games and the other one. They now play one game of which the chances are such that if the first wins, he will win the entire wager that is at stake, that is to say, 64 pistoles. If the other wins, they will be two to two and in consequence, if they wish to separate, it follows that each will take back his wager, that is to say, 32 pistoles.

Consider then, Monsieur, that if the first wins, 64 will belong to him. If he loses, 32 will belong to him. Then if they do not wish to risk this game, and put themselves at risk without playing it (*s'ils ne veulent point hasarder cette partie et se hasarder sans la jouer*), the first should say, 'I am sure of 32 pistoles, for even a loss gives them to me. As for the 32 others, perhaps I will have them and perhaps you will have them; the risk is equal (*le hasard est égal*). Therefore let us divide the 32 pistoles in half, and give me the 32 of which I am certain besides.' He will then have 48 pistoles and the other will have 16."[28]

Commentators have often dwelt on the increasingly complex examples of calculation that Pascal examines in the course of the correspondence, which certainly influenced later treatises on probability. But we have thus lost sight of what Pascal aimed at with the solution of the problem, namely, to enable a decision about *reality* through an exact probabilistic assessment of *possibilities*. As suggested by the very phrase "interrupted game," it was a matter of suspending the real game in order to replace it with a calculation of risks, which made it possible to decide the division of the stake that was most equitable and useful in this perspective. The expression *se hasarder sans jouer* is particularly significant; the one who calculates probability relies on risk without actually taking a risk, that is to say, he leaves reality and at the same time transforms chance—*l'hasard*—into a principle allowing him to decide on reality. This means that probability is never punctually realized as such, nor does it concern a single real event, but, as Majorana understood, it allows us to intervene in reality, as considered from a special perspective, in order to govern it.

The concept of *hasard* developed in the letter to Fermat reappears in Pascal precisely where we would least expect it, that is, in the well-known passage about the wager (*pari*) with which the believer wagers on the existence or inexistence of God, and on the uncertainty of eternal life as opposed to earthly pleasures. Let us suppose that heads corresponds to the existence of God and eternal life and tails to his inexistence, and that the gamblers are obliged to wager. The disparity between the infinity of possible gains and the finitude of the equally possible loss requires that we do not take account of a probability that could be calculated but decide only on the basis of the stakes. The uncertainty of the gain is in fact consubstantial with the game, and the calculation is used precisely in order to decide in a situation of uncertainty and not to ensure an impossible certainty. "It is no good saying that it is uncertain whether you will win, that it is certain that you are taking a risk (*il est certain qu'on hasarde*), and that the infinite distance between the *certainty* of what you are risking and the *uncertainty* of what you may gain makes the finite good you are certainly risking equal to the infinite good that you are not certain to gain. This is not the case. Every gambler takes a certain risk (*hasarde*) for an uncertain gain, and yet he is taking a certain finite risk for an uncertain finite gain without sinning against reason."[29] If the risk of winning is equal to that of losing, but what is at stake is, on the one hand, something infinite and, on the other, something finite, it is clear that the gambler cannot but take this into account. The same calculation that in the "interrupted game" recommended us to divide the stakes of the last game into two equal parts, suggests us here—given that the stake is not divisible—to bet on what would be a decidedly higher gain. The wager with which I decide upon my life depends on the stakes and not on verification of its probability of winning—which is, moreover, impossible.

10. Modern statistics takes for granted the idea that probability is independent of its empirical verification. The recurrent tendency ingenuously to consider the distribution of frequencies of a given value as an objective property of the system under examination

is therefore stigmatized as a "naturalistic fallacy."[30] It is in fact important not to confuse the calculation of probability with its experimental verification. If in flipping a coin the observed frequency of heads and tails is not 0.5 but 0.7, or that of a dice throw is not 1/6 but 3/6, this does not mean that the probabilistic theorem is wrong, but that it is probable that the coin or dice is unbalanced and needs to be replaced.

Statistics is not a science that aims at an experimental knowledge of the real; rather, it is the science that enables us to take decisions in uncertain conditions. For this reason, as was evident in its origins in dice games, the concept that underlies probability is not so much frequency over a long period of time as the "critical odds for a bet,"[31] in which frequency is used not to infer a supposedly real property of the system, but—precisely as happens in quantum mechanics—to corroborate or refute a previous conjecture (which is fully comparable to a wager).

11. The idea that potency or possibility (*dynamis*) should be considered as a way of being along with actuality (*energeia*) dates back to Aristotle. Against the Megarians, who claimed—not without good reason—that potency exists only in the act, that is, in the occurrence of its exercise, Aristotle objects that if this were the case we could not consider an architect to be

an architect when he is not building or call a doctor who is not exercising his art, "doctor."[32] In other words, potency (which Aristotle attributes especially to human techniques and knowledge) is constitutively defined by the possibility of its exercise, its power to be or not to be and to pass or not to pass to the act. According to all the evidence, what is here in question is the way of being of possibility, which indeed exists in the form of not yet being in act, that is, of existing independently of its actual realization. For this reason Aristotle can affirm that "every potency is the impotency [that is, the potency not to be] with respect to the same [thing] of which it is the potency." The possibility of suspending its own realization is inherent to the very concept of potency.

Although he affirms without reservation the existence of potency, not without contradiction, Aristotle decidedly subordinates the sphere of *dynamis* to that of reality and *energeia*. *Energeia* precedes possibility according to both concept and substance, not only because the adult necessarily precedes the child and man precedes his seed, but also because everything that is potential tends toward the act as its own end. Living beings thus have the possibility of seeing in order to actually see, and not vice versa, and mankind has the possibility of knowing in order to know, and not just to have the faculty of knowing. For this reason, Aristotle can state that, on the one hand, if there are no impediments, what is possible will naturally pass to the act, and, on the other, it does not make sense to speak of possibility with regard to things that necessarily exist.[33]

Aristotle was not familiar with the concept of probability, but he addressed chance (which he called *automaton* and *tuche*) in relation to his doctrine of the four causes (material, formal, efficient, and final). Chance is a non-cause, or an accidental cause, which we refer to when events that seem to have been produced because of a given final cause are instead produced accidentally and unexpectedly. If a man who goes to a certain place but without the intention of collecting a debt accidently meets his debtor, who is himself there by chance and pays his debt, we will say that the collection of the debt occurred *apo tuches*, because of chance.[34]

It goes without saying that Aristotle rules out that there can be a science of chance and what is accidental: "There can be no science of the accidental, because every science has as its object that which is so always or usually, and the accidental falls under neither of these descriptions. . . . Chance [or fortune, *tuche*] is the accidental cause of things that happen because of a decision in view of an end. Hence chance and thought have the same sphere of action, for there is no decision without thought. There are infinite causes from which fortuitous accidents may come about; for this reason, fortune is inscrutable to human reason and is a cause only accidentally, but in an absolute sense is a cause of nothing."[35]

If we try to define probability in Aristotle's terms, we may say that it is a potency emancipated from its hierarchical subjection to the act. Insofar as it has secured an existence that is independent of its actual realization, such a possibility tends to replace reality and thus to become the object of a science of the accidental—unthinkable for Aristotle—that considers possibility as such, not as a means of knowing the real, but as a way of intervening in it in order to govern it. The analogy with Aristotelian *dynamis* is all the stronger here since the latter was indeed the specific dimension of human techniques and knowledge. In *De Anima*, Aristotle thus comes to define the intellect as "a being whose nature is potential being" and compares it to a writing tablet on which nothing has yet been actually written. What happened in modern statistics and quantum physics is that the writing tablet—pure possibility—replaced reality, and knowledge now knows only knowledge itself. Following the beautiful image given by a medieval philosopher, what does not stop being written on the tabula rasa of the intellect is not reality but the very potency of thought, "as if the letters wrote themselves on the tablet."

12. If we now return to the motivation for Majorana's disappearance, we may argue that the article we examined earlier shows beyond doubt that he had clearly seen the consequences of the introduction of probability into physics. If we need to rule out every psychological interpretation—as he never tires of repeating that we should—then the meaning of his decision to disappear must somehow refer to this problematic context. The limit of Sciascia's interpretation, however subtle, is that, if we suppose that Majorana abandoned physics because he had grasped that it led to the atomic bomb, then his decision to disappear and retreat to a monastery appears to be a consequence of the dismay (Sciascia speaks of "disquiet" and "fear") caused by the disastrous path science had taken. This means locating the decision in that psychological dimension that Majorana wanted to dismiss; just like the "Ibsen heroine" evoked in the letter to Cardelli (probably the character of Nora in *A Doll's House*, who abandons her husband because she has lost her moral certainties), Majorana renounced physics because he had lost faith in science.

If we instead accept that his case is intentionally "different"—as Majorana insistently demands, and against the biased testimonies of his colleagues from the Institute of Physics regarding the "eccentricity" and "abnormality" of the "Saracen" (as Amaldi defines him, in a friendly spirit)—then his disappearance must contain in itself, along with its motivations and meaning, a decisive objection to the probabilistic nature of quantum mechanics. It is worth recalling that when Majorana met Fermi, the latter was well known for the statistical model that is still named after him (depending on the statistical model they follow, all particles are divided into bosons, which accord with the statistics of Bose and Einstein, and fermions, which accord with the statistics of Fermi and Dirac). As Simone Weil sensed a few years later, Majorana immediately realized that, as soon as we assume that the real state of a system is in itself unknowable, statistical models become essential and cannot but replace reality (as he wrote in the article we have cited, "the result of any measurement seems, therefore, to be concerned with the state the system is led to during the experiment rather than with the unknowable state of the system before being perturbed").

The hypothesis I intend to put forward is that, if quantum mechanics relies on the convention that reality must be eclipsed by probability, then disappearance is the only way in which the real can peremptorily be affirmed as such and avoid the grasp of calculation. Majorana turned his very person into the exemplary cipher of the status of the real in the probabilistic universe of contemporary physics, and produced in this way an event that is at the same time absolutely real and absolutely improbable. When, on that evening in March 1938, Majorana decided to vanish into thin air and render ambiguous every experimentally detectable trace of his disappearance, he asked science the question that still awaits its unrequestable [*inesigibile*] and yet ineluctable answer: *What is real?*

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The Value of Statistical Laws in Physics and Social Sciences

By Ettore Majorana
translated by Rosario Nunzio Mantegna

1. The concept of nature according to classical physics

The study of the true or hypothetical relations between physics and other sciences has always been of notable interest due to the special influence that physics has played on the general course of scientific thought in modern times. It is known that the laws of mechanics have been seen for a long time as the ultimate kind of human knowledge about nature. Many scholars have also believed that the imperfect

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notions of other sciences should eventually be related back to the kind of notions observed in mechanics. The above concept justifies the study we consider here.

The exceptional credit of physics evidently comes from the discovery of the so-called exact laws. These laws consist of relatively simple formulas, originally "excogitated" starting from fragmentary and approximate empirical indications, which turn out to be of universal validity both when these laws are applied to new orders of phenomena and when the progressive improvement of the art of experiments allows one to verify them in a more and more rigorous way. It is known to everybody that according to the fundamental concept of classical mechanics the motion of a physical body is completely determined by the initial conditions (position and velocity) of the body and by the forces that are applied to it. On the nature and size of forces that may be present in material systems, the general laws of mechanics state only some condition, or limitation, that always must be verified. Such a characteristic, for example, has the principle of action and reaction. To this principle one has added, more recently, other general rules such as the ones concerning constrained systems (principle of virtual work) or elastic reactions and, even more recently, the mechanical interpretation of heat and also the energy conservation principle, which is seen as a general principle of mechanics. Apart from these general indications, it is however a special task of physics to discover, case by case, all that is needed to effectively apply the principles of dynamics, which is the knowledge of all forces acting in the system being investigated.

In one case, however, it has been possible to find the general expression for forces that are present between material bodies. This occurs in the case where material bodies are isolated one from the other and therefore the forces are reciprocally acting at distance only. In this last case, if we do not consider electromagnetic forces, which were discovered in the nineteenth century and which manifest themselves only under specific conditions, the only force acting is the force of gravitation, whose notion was suggested to Newton from the mathematical analysis of the Keplero laws. The Newton law is typically applicable to the study of the motion of celestial bodies, which being separated by immense empty spaces can indeed influence each other only through action at a distance. As is known, this law is indeed sufficient to predict in any aspect and with a beautiful accuracy the complex dynamics of our planetary system. Only one minute exception, the secular displacement that undergoes Mercury's perihelion, constitutes one of the major experimental proofs of the recent theory of general relativity.

The sensational success of mechanics applied to astronomy has encouraged the assumption that more complicated phenomena of common experience must also be in the end reconducted to a similar mechanism, albeit more general than the gravitational law.

According to this point of view, which has produced the mechanistic conception of nature, the entire material universe evolves obeying an inflexible law, where the state of the universe at a given instant of time is completely determined from its state at the previous instant of time. This is a sign of the fact that the future is implicit in the present. In other words, the future can be predicted with absolute certainty provided that the actual state of the universe is completely known. This fully deterministic conception of nature has had numerous confirmations since its introduction. Further developments of physics, from the discovery of the electromagnetism laws to the ones for the theory of relativity, have suggested a progressive enlargement of the principles of classical mechanics. On the other hand, they have vigorously confirmed an essential point, namely, the complete causality in physics. It is not disputable that determinism has the principal and almost exclusive merit of having made possible the magnificent modern development of science, and also in fields very far removed from physics. Determinism, which does not leave any rule to human freedom and forces one to consider all the phenomena of life as illusory, implicates a real cause of weakness. This is the irremediable and immediate contradiction with the most certain data of our conscience. Indeed, how the effective and, most probably, definitive overtaking of determinism has occurred in the physics of recent years will be discussed later. Indeed our final aim will be to illustrate the renovation that the traditional concept of statistical laws must undertake as a consequence of the new direction followed by contemporary physics. At the present stage we still wish to keep the classical conception of physics. This is done not only for its enormous historical interest but also because classical physics is still the only physics largely known except to specialists.

Before ending this introductory part, we wish to point out that criticism of determinism has been raised in recent times. The philosophical reaction, when appropriate, did not extend beyond the philosophical field, and essentially it has left the scientific problem untouched. An attempt devoted to solve this specific scientific problem can be found in the work of G. Sorel.[1] He is an author representing the pragmatism or philosophical current in pluralism. According to the followers of this movement, an effective heterogeneity of natural phenomena excludes that a unitary knowledge of them might exist. Each scientific principle should be applied to a delimited ambit of phenomena without the possibility of achieving universal validity. G. Sorel develops the criticism of determinism by stating that this concept would apply only to phenomena which he calls *artificial nature*. These phenomena are characterized by the fact that they do not occur in the presence of an appreciable *degradation* of energy (in the sense of the second principle of thermodynamics). These phenomena sometimes occur spontaneously, especially in astronomy, where they constitute phenomena of simple observation. However, more often these phenomena are investigated in laboratories by experimenters. They devote special care to eliminating all possible passive resistances. The other phenomena, which belong to the common experience or to *natural nature* and occur in the presence of passive resistances, would not be controlled by precise laws but they should be affected by chance to a various degree. Sorel explicitly uses a metaphysical principle of G. B. Vico. We do not want to discuss here the arbitrary accentuation given to a specific aspect of science as it has been represented in an epoch which is no longer ours. Here we have to note that the pragmatist principle of judging the scientific doctrines on the basis of their effective usefulness does not justify the attempt of condemning the ideal of the unity of science. This idea has acted as a powerful stimulus to the progress of science many times.

2. The classical meaning of statistical laws and social statistics

To fully understand the meaning of statistical laws according to mechanics, one needs to recall a hypothesis about the structure of matter, which was already familiar to the ancients and entered the domain of science due to Dalton at the beginning of the nineteenth century. He first recognized in the atomic hypothesis the natural explanation for the general laws of chemistry, which had been recently discovered. According to modern atomic theory, which has been definitively confirmed with specific methods of physics, there exists an amount of species of indivisible elementary particles, or *atoms*, of the same number of simple chemical elements. The union of two or more atoms of the same or different species forms the *molecules*. Molecules are the last particles in which one can divide a definite chemical substance, which are capable of independent existence. Single molecules (and sometimes also atoms within molecules) are not located in a fixed position, but rather they undergo a very fast movement of translation and rotation around themselves. The molecular structure of gases is very simple. Indeed single molecules of gases can be considered as rather independent in common conditions. The relative distances between molecules are very large with respect to their extremely limited dimensions. By applying the inertial principle one concludes that their motion is rectilinear and uniform most of the time. The motion undergoes abrupt changes of direction and speed only when impacts occur. Supposing we exactly know the laws governing the mutual influence of molecules, we should expect, in terms of general principles of mechanics, that it is enough to know the position of all molecules and their translational and rotational velocities *in addition* in order to predict *in principle* the exact state of the system after a certain time interval (although these calculations could be too complex to be effectively realized in practice). The use of the deterministic scheme, which is specific to mechanics, is however subject to a real limitation of principle when we take into account the fact that the *usual* methods of observation are not able to provide us with the exact instantaneous conditions of the system. They provide us only with a certain number of global observables. For example, by considering the physical system given by a certain amount of gas, it is sufficient to know the gas pressure and density to determine other variables, such as the temperature, the viscosity coefficient, etcetera, that could be the object of specific measurements. In other words, in the present example the values of pressure and density are sufficient to fully determine the state of the system *from a macroscopic point of view*, although they are evidently not sufficient to establish the exact internal structure of the gas at each time, that is, the distribution of position and velocity of all molecules.

To discuss with clarity and conciseness and without any mathematical apparatus, the nature of the relationship between a *macroscopic state* (*A*) and a real state (*a*) of a system, we need to relax precision to a certain degree, although we avoid altering the true nature of the facts in an essential way. We therefore need to understand that the observed *macroscopic state* (*A*) corresponds to a large number of possibilities *a, al, all* . . . Our observations do not allow us to distinguish among them. The *number N* of these internal possibilities would be infinite within the framework of classical theory, but quantum theory has introduced an essential discontinuity in the description of natural phenomena, so that the number (*N*) of these possibilities in the structure of a system is indeed finite although huge. The value of *N* gives a measure of the degree of hidden indeterminacy of the system. It is however practically preferable to consider a quantity proportional to its logarithm

$$S = K \log N$$

K being the Boltzmann universal constant, which has been determined by imposing that S coincides with the entropy, which is a known quantity of thermodynamics. Indeed entropy is a physical quantity with the same importance as weight, energy, etc. This is mainly because entropy is an additive quantity in the same manner as the others. In other words, the entropy of a system composed of several independent parts is equal to the sum of the entropy of each single part. To prove this, it is enough to observe that the number of potential possibilities of a composed system is evidently equal to the product of analogous numbers describing the constituent parts together with the known elementary rule establishing the correspondence between the product of two or more numbers and the sum of their logarithms.

In general, there are no difficulties in how to determine the ensemble of internal configurations *a, al, all* . . . corresponding to a macroscopic state *A*. However, one can discuss if all the distinct possibilities *a, al, all* . . . should be considered as equally probable.

According to the ergodic or quasi-ergodic hypothesis, which is widely believed to be verified, whether a system persists in a state *A* indefinitely, then one can state that it spends an equal fraction of its time in each of the configurations *a, al, all* . . . Therefore one considers all possible internal determinations as equally probable. This is indeed a new hypothesis because the universe, which is far from being in the same state indefinitely, is subjected to continuous transformations. We will therefore admit as an extremely plausible working hypothesis, whose far-reaching consequences could sometimes not be verified, that all the internal states of a system are *a priori* equally probable for specific physical conditions. Under this hypothesis, the *statistical ensemble* associated with each macroscopic state *A* turns out to be completely defined.

The general problem of statistical mechanics can be summarized as follows: Suppose the initial state *A* has been statistically defined; which predictions, therefore, are possible about its state at time *t*? At first sight, it may seem that this definition is too limited because other *static* problems can be considered in addition to the dynamic problem. For example, what is the temperature of a gas whose pressure and density are known? Similarly this applies in all cases when one wishes to determine a quantity of interest from certain known characteristics of the system, which are sufficient to define its state. The distinction can be formally ignored because by incorporating appropriate measuring instruments in the system, one can always go back to the previous case.

Let us suppose that the initial state of the considered system is described by a statistical ensemble *A* = (*a, al, all* . . .) of possible cases which are, as stated before, equally probable. Each of these specific determinations changes during time according to a law that we have to consider strictly causal in agreement with the general principles of mechanics. Therefore the system moves from the series *a, al, all* . . . to another specific series *β, βl, βll* . . . after a certain time. The statistical ensemble (*β, βl, βll* . . .), which is also constituted of *N* equally probable elements as the original ensemble *A* (Liouville theorem), defines all the possible predictions for the system evolution. Due to reasons that only a complex mathematical analysis could make precise, in general it turns out that all simple cases belonging to the series *β, βl, βll* . . . , *except a negligible number of exceptions, wholly* or *in part*, constitute a new statistical ensemble *B* defined from a well-determined macroscopic state as in *A*. We can therefore state the *statistical law* according to which there is the practical certainty that the system should move from *A* to *B*. Due to the above discussion, the statistical ensemble *B* is at least as large as *A*. It contains a number of elements not less than *N*. It therefore follows that the entropy of

B is equal to or larger than that for *A*. In the presence of any transformation occurring in *agreement with statistical laws*, one therefore has a constant or increasing entropy, never a decrease. This is the statistical foundation of the famous second principle of thermodynamics.

It is worth noting that the transition from *A* to *B* can be considered certain from a practical point of view. This explains why historically the statistical laws have been originally considered as accurate as the laws of mechanics and only because of the progress of theoretical investigation has one subsequently recognized their true character. The statistical laws include a large amount of physics. Among the most widespread applications, we cite the gas state equation, the diffusion theory, the theory of thermal conductance, of viscosity, of osmotic pressure and several other similar ones. A specific mention is deserved for the statistical theory of irradiation, which introduces the *discontinuum* symbolized by the Planck constant for the first time in physics. Moreover there is an entire area of physics, thermodynamics, whose principles, although directly based on experience, can be related to the general notions of statistical mechanics. On the basis of what has been done before, one can summarize the meaning of statistical laws within classical physics in the following way: 1) natural phenomena obey a complete determinism; 2) the *customary* observation of a system does not allow one to identify the internal state of the system but only the ensemble of very large possibilities which are macroscopically indistinguishable; 3) by establishing a plausible hypothesis for the probability of different possibilities and by assuming valid the laws of mechanics, the probability calculus allows the probabilistic prediction of future phenomena. We are now ready to examine the relation present between the laws established by classical mechanics and the empirical regularities, which are known by the same name especially in social sciences.

First of all, one should realize that the formal analogy could not be more stringent, for example, when one states the statistical law: “In a modern European society the annual marriage rate is about 8 for 1,000 inhabitants.” It is clear enough that the investigated system is defined only with respect to certain global characters by deliberately renouncing the investigation of additional information, such as, for example, the biography of all individuals composing the society under investigation. This knowledge would certainly be useful in predicting the phenomenon with a precision and an accuracy higher than in the case for a generic statistical law. This is not different from when one defines the state of a gas by simply using pressure and volume and by deliberately renouncing investigation of the initial conditions for all single molecules. A substantial difference could indeed be detected in the definite mathematical character of the physics statistical laws, which has to be compared with the empirical character of social statistical laws. It is however plausible to attribute the empirism of social statistics (with the term empirism we precisely mean the lack of reproducibility of their results *in addition to the random part*) to the complexity of the considered phenomena. This last aspect implies that it is not possible to precisely define the conditions or the content of the law. On the other hand, physics also has empirical laws when it is studying phenomena of applied interest. Examples are the laws of friction among solid bodies or the magnetic properties of several types of iron and other similar materials. Lastly, one could express the special importance of the difference in the measurement methods, which are global in physics (it is sufficient to read a measurement instrument to know the pressure of a gas in spite of the fact that pressure arises from the sum of independent pulses that single molecules transmit to the walls), whereas in social statistics individual facts are recorded. This difference is however not an absolute antithesis as it is proved by the possibility of various indirect methods of detection. By admitting the arguments that suggest the existence of a real analogy between physics and statistical laws, we are induced to assume as plausible that the social statistical laws are the most direct proof that an absolute determinism also governs human facts in a way similar as physics statistical laws imply a rigid determinism. This is an argument that has had much better fortune because, as said before, one has detected the tendency to see the causality of classical physics as a model of universal value for independent reasons. Here it would be out of place to reopen old and never concluded discussions, but we wish to recall as a generally admitted fact that the absence of conciliation among contrasting intuitions of nature has for a long time played a role in modern thought and in moral values. It is therefore not just a scientific curiosity the announcement that physics has been forced to abandon its traditional course by rejecting the absolute determinism of classical mechanics in a definitive manner in recent years.

3. The new concepts of physics

It is impossible to present with some completeness in a few lines the mathematical apparatus and the experimental content of quantum mechanics.[2] We will therefore limit ourselves to some short description. There are experimental facts, known for a long time (interference phenomena), which undoubtedly support an undulatory theory of light. Conversely, other recently discovered facts (Compton effect) suggest, no less convincingly, the opposite corpuscular theory. All attempts of settling this contradiction within classical physics have been unsuccessful. This may not seem so relevant except that these inexplicable facts and others no less inexplicable and those of the most differing nature and lastly almost all phenomena known to physicists, and up to now insufficiently understood, have been explained with a unique and wonderful simple explanation. This is the one contained in the principles of quantum mechanics. This extraordinary theory is as solidly founded on experience as much as, perhaps, any other one has ever been. The criticism that it has received and is receiving is not concerned at all with the legitimacy of its use for effective prediction of phenomena, but rather the widespread opinion that the new approach should be conserved and perhaps even grow in future developments of physics. The specific aspects of quantum mechanics as compared with classical mechanics are as follows.

a. There are no laws in nature which express a fatal succession of phenomena. Basic laws governing elementary phenomena (atomic systems) have a statistical character. They establish only the *probability* that a measure performed in a prepared system will give a certain result. This occurs in spite of the means by which we are disposed to determine the initial state of the system with the highest possible accuracy. These statistical laws indicate a real deficiency of determinism. They have nothing in common with the classical statistical laws where uncertainty of results derives from a voluntary renunciation for practical reasons to investigate the initial conditions of physical systems in the most minute aspects. Below we will see a well-known example of this new kind of natural law.

b. A certain lack of *objectiveness* in the description of phenomena. Any experiment performed on an atomic system exerts a finite perturbation on it that cannot be eliminated or reduced for principle reasons. The result of any measure seems, therefore, to be concerned with the state where the system is led during the same measurement rather than the undetectable state in which the system was before the perturbation. This aspect of quantum mechanics is without doubt more disquieting, that is, farther from our customary intuitions, than the simple lack of determinism.

Among the probabilistic laws concerning basic phenomena, the one governing radioactive processes has been known for a long time. Any atom of radioactive matter has a probability mdt in a time interval dt of transforming itself after the emission of an α particle (a helium nucleus) or, in other cases, of a β particle (an electron). The *mortality rate m* is constant, i.e., independent of the atom age. This gives a specific form to the *survival curve*, which is exponential. The mean lifetime is 1/*m*, and one can estimate the *probable lifetime*, sometimes called the *transformation period*, in an elementary way. Both quantities are independent of the atom age. Indeed the atom does not manifest any sign of real aging when time elapses. Several methods of observation and automatic recording of the single transformation occurring within a radioactive matter exist. It has been therefore possible to verify through direct statistical measurements and applications of probability calculus that single radioactive atoms do not undergo any reciprocal influence or any external influence concerning the instant of transformation. Indeed the number of disintegrations occurring in a certain time interval is subject to random fluctuations, that is, to the probabilistic character of the individual law of transformation.

Quantum mechanics has taught us to see in the exponential law of radioactive transformations a basic law which is not reducible to a simpler causal mechanism. Of course the statistical laws concerning complex systems known in classical mechanics retain their validity according to quantum mechanics. Quantum mechanics modifies the rules of the determination for internal configurations in two different ways, depending on the nature of the physical systems, ending up with the statistical theories of Bose-Einstein and Fermi. However, the introduction in physics of a new kind of statistical law or, better, simply a probabilistic law, which is hidden under the customary statistical laws, forces us to reconsider the basis of the analogy with the above-established statistical social laws. It is indisputable that the statistical character of social laws derives at least in part from the manner in which the conditions for phenomena are defined. It is a generic manner, that is, strictly statistical, allowing an infinite complex of different concrete possibilities. On the other hand, by remembering what has been said above on the *mortality tables* of radioactive atoms, we are induced to ask ourselves whether there also exists here a real analogy with social facts, which are described with a somewhat similar language.

At first sight something seems to exclude this. The disintegration of an atom is a simple fact, which is unpredictable and which occurs abruptly and in isolation after a wait of thousands and even billions of years, whereas nothing similar occurs for facts which are recorded from social statistics. However, this is not an insurmountable objection.

The disintegration of a radioactive atom can force an automatic counter to detect it with a mechanical effect, which is possible thanks to a suitable amplification. Common laboratory set-ups are therefore sufficient to prepare for whatever complex chain of rich phenomena is *produced* from an accidental disintegration of a single radioactive atom. From a scientific point of view nothing prevents one from considering that an equally simple, invisible and unpredictable vital fact could be found at the origin of human events. If this is so, as we believe it is, the statistical laws of social sciences increase their function. Their function is not only of empirically establishing the resultant of a great number of unknown causes, but, above all, it is to provide an immediate and concrete evidence of reality. The interpretation of this evidence requires a special skill, which is an important support of the art of government.

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Notes

What Is Real?

1. Leonardo Sciascia, *The Moro Affair and The Mystery of Majorana* (Manchester: Carcanet, 1987), p. 170. [Where necessary, existing English translations have been modified. Bibliographical references are provided only when the author provides them. I would like to thank Giorgio Agamben and Michael Lewis for their insightful comments on my manuscript—Trans.]

2. Ibid., p. 174.

3. Ibid., p. 155.

4. Simone Weil, *Sur la science* (Paris: Gallimard, 1966), p. 121.

5. Ibid., pp. 126–127.

6. Ibid., p. 128.

7. Ibid., p. 130.

8. Ibid., p. 147.

9. Ibid., p. 148.

10. Ibid., p. 150.

11. Ibid., p. 155.

12. Ibid., p. 193.

13. Ibid., p. 204.

14. The reader should bear in mind that the Italian term for "chance" is *caso*, which also means "case."—Trans.

15. Weil, *Sur la science*, pp. 150–151.

16. Ibid., p. 152.
17. Ibid., p. 155.
18. Ibid., p. 156.
19. Ibid., p. 131.
20. Ibid., p. 157.
21. Louis De Broglie, *New Perspectives in Physics* (Edinburgh: Oliver & Boyd, 1962), p. 149.
22. Niels Bohr, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?," in *Physical Review* 48 (October 15, 1935), p. 702.
23. Erwin Schrödinger, "The Present Situation in Quantum Mechanics," in *Proceedings of the American Philosophical Society*, vol. 124, pp. 323–338.
24. Hieronymi Cardani, *Opera Omnia*, vol. 1 (Lyon, 1663), p. 264.
25. Ibid., p. 266.
26. Ibid., p. 270.
27. Henry Poincaré, *Science and Hypothesis* (London: Walter Scott Publishing, 1905), p. 184.
28. Blaise Pascal, *Les lettres de Blaise Pascal* (Paris: Crès, 1922), p. 193.
29. Blaise Pascal, *Pensées* (London: Penguin, 1995), p. 124.
30. Paolo De Vineis, *Modelli di rischio* (Turin: Einaudi, 1990), p. 29.
31. Ibid., p. 28.
32. Aristotle, *Metaphysics*, 1046b, 29.
33. Ibid., 1050b, 18.
34. Aristotle, *Physics*, 197a.
35. Aristotle, *Metaphysics*, 1065a.

The Value of Statistical Laws in Physics and Social Sciences

1. G. Sorel, *De l'utilité du pragmatisme*, Cap. IV (Paris, 1921).
2. The reader desiring to study thoroughly the knowledge in this matter by avoiding where possible mathematical difficulty can consult W. Heisenberg, *Die Physikalischen Prinzipien der Quantentheorie* (Lipsia, 1930).

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Over eighty years ago, Ettore Majorana, a brilliant student of Enrico Fermi, disappeared under mysterious circumstances while going by ship from Palermo to Naples. How is it possible that the most talented physicist of his generation vanished without leaving a trace? It has long been speculated that Majorana decided to abandon physics, disappearing because he had precociously realized that nuclear fission would inevitably lead to the atomic bomb. This book advances a different hypothesis. Through a careful analysis of Majorana's article "The Value of Statistical Laws in Physics and Social Sciences," which shows how in quantum physics, reality is dissolved into probability, and in dialogue with Simone Weil's considerations on the topic, Giorgio Agamben suggests that, by disappearing into thin air, Majorana turned his very person into an exemplary cipher of the status of the real in our probabilistic universe. In so doing, the physicist posed a question to science that is still awaiting an answer: *What Is Real?*

GIORGIO AGAMBEN *is a contemporary Italian philosopher and political theorist whose works have been translated into numerous languages. His most recent title with Stanford University Press is* Karman *(2018).*

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